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Decoupling Scheme for a Cryogenic Rx-Only RF Coil for 13C Imaging at 3T

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Synopsis

In this study we evaluate the different active decoupling schemes that can be used to drive an Rx-only coil, in order to determine the optimal design for ^{13}C MRI at 3T. Three different circuit schemes are studied: two known ones (with regular series and parallel tuning respectively), and a novel one which we found to be optimal for this case. The circuits have been cooled to 77K to reduce coil noise. Preliminary tests with the preamplifier cooled to 77K for reduction of noise figure, are also reported.

Purpose

Hyperpolarized Metabolic ^{13}C MR has attracted a lot of attention in the latest years, e.g. due to its potential to be used for early indication of disease[1]. The lower Larmor frequency of ^{13}C entails lower coupling to the sample, which leads to less sample noise for physically small coils. This emphasizes the effect of losses in the lumped elements used for tuning/matching/decoupling, which can easily become dominant for coils with low resistance. In this study we propose a new active decoupling scheme which provides lower losses than traditional designs. A loop coil with 50 mm diameter (2.3 mm copper wire, L≈95 nH) is chosen as a detector, since it is a convenient size as building block in coil arrays. The coils are connected to a low input impedance preamplifier, which allows for coil decoupling schemes when used in an array coil[2].

Methods

Fig. 1 depicts the three Rx-Only circuit schemes studied:

- Coil 1: series tuned coil with segmented tuning capacitor, widely used because it allows preamp decoupling schemes.

- Coil 2: parallel tuned coil with two balanced matching capacitors, and an active decoupling trap formed with one of the tuning capacitors.

- Coil 3: newly proposed parallel tuned coil with a balanced matching network, where one of the matching capacitors is split and used to create a trap together with the tuning capacitor (opening the loop at the test frequency). The non-split matching capacitor is also used to create an additional trap which effectively breaks the ground path of the loop and improves the decoupling.

The preamplifier (WanTCom model WMA32C) has a nominal input impedance of 3 Ω and a measured noise figure (NF) at room-temperature of 0.8 dB at 32.13 MHz. It is not rated for low temperatures.

Results

The three coils described above were first simulated using CST. Capacitor losses are modelled using its Equivalent Series Resistance (ESR). Capacitors from the CHB series (TEMEX Ceramics, France) were used. We found that capacitors ranged between 22 and 470 pF had an ESR of about 20 mΩ, while capacitors of 1000 pF and higher had about 40 mΩ. The coils were fabricated and characterized on the bench. Then they were connected to a clinical scanner (GE Signa 3T), and images at room temperature were taken using a spherical phantom with 30 mm diameter and filled with ^{13}C enriched bicarbonate. The results obtained are summarized in the upper part of Table 1. The measurements agree very well with the simulations, which shows that the model used for the capacitors is good and that the losses in the circuitry are dominated by the ESR of the capacitors. Also the SNR results obtained at the scanner are consistent, and show proportionality to the Q-factor. The effect of capacitor losses is even more relevant if the coils are cooled. Simulations and bench measurements with the coils cooled to 77K have been performed, and are shown in Table 1. In this case, we considered for the simulations that the ESR of the capacitors was reduced to half when cooled down to 77K, which showed good agreement with bench measurements. Bench measurements with the preamp cooled to 77K show that, under some conditions, can provide a NF of 0.1 dB at the test frequency.

Discussion

The results obtained show that for some MRI experiments at lower frequencies, the decoupling circuit can have a very important effect on the total losses. We found that, when the coil resistance is very low, the losses of the resonator can easily be dominated by the ESR of the tuning capacitor[s]. In this case, it is advantageous to close the loop with only one capacitor, such that the resistance added to the resonator is minimized. To prevent the loop from short-circuiting the DC decoupling circuit, an extra matching capacitor needs to be added, and used to create the tuned trap activated by the decoupling signal. However, since this capacitor is already out of the resonator itself, the current flowing through it is low. The results obtained here show that, depending on the balance between loop, circuit and sample losses, adding segmenting capacitors may be counterproductive in some cases.

Conclusion

A novel circuit scheme for receive-only RF coils is proposed, which reduces significantly the coil losses for coils with very low resistance. For ^{13}C at 3T a 20% SNR improvement was obtained at room temperature (compared to traditional schemes). At 77K the Q more than doubles and the NF of the preamplifier reduces to 0.1 dB.

Acknowledgements

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References

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Figures

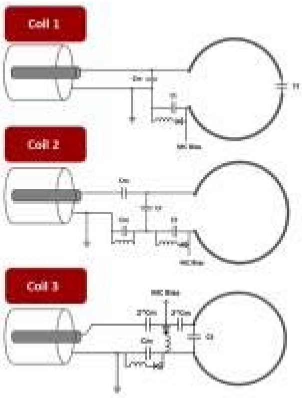

Figure 1. Different circuit schemes evaluated in this study: 1) Series tuned (C_m= 2000 pF, C_t= 470 pF); 2) Parallel tuned (C_m= 47 pF, C_t= 470 pF); 3) Parallel tuned with split matching capacitor (C_m= 22 pF, C_t= 230 pF).

	Temperature [K]	L [nH]	R_L [mΩ]	R_M [mΩ]	$Q_{simulation}$	$Q_{measurement}$	$SNR_{...}$
		Simulations				Measurements	
Coil 1	298	95.2	27	62	220	216	41.2
Coil 2		95.2	27	38	303	293	58.8
Coil 3		95.2	27	19	401	420	62.5
Coil 1	77	94.3	12	48	383	485	-
Coil 2		94.3	12	19	690	688	-
Coil 3		94.3	12	19	690	648	-

TABLE 1. Results from Simulations, Bench and Scanner Measurements. (L is the inductance of the loop, R_L its resistance and R_M the resistance added to the resonator by the circuit elements).